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Anvendelse av polarisasjon for å skille ulike typer informasjon

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Oppfinnelsens område

Den foreliggende oppfinnelse vedrører bruk av polarisasjon for å skille QoS klasser, samt å skille nyttelast og hode i pakker innenfor kommunikasjonsnettverk. Mer generelt omhandler oppfinnelsen en ny og forbedret utnyttelse av polarisasjonstilstander i sin alminnelighet innenfor alle typer kommunikasjonsnettverk.

Oppfinnelsens bakgrunn

Med innføringen og utviklingen av optiske nett er det et mål å redusere kostnadene for overføring av data i Tele og datanettverk. Et viktig moment for kostnadsreduksjon er i økende grad å redusere antall signalkonverteringer mellom optisk og elektronisk form. En slik reduksjon vil gi et redusert antall komponenter i nettverkselementene og redusere behovet for elektronisk signalprosessering. Disse momentene gir igjen potensiale for en kostnadsreduksjon.

Ved erstatning av elektroniske nettverkselementer med optiske nettverkselementer er det derfor nødvendig at de optiske nettverkselementene har en funksjonalitet som kan fungere effektivt i et pakkesvitsjet nettverk. I denne forbindelse er det de seneste årene gjort mye forskning på optisk pakkesvitsjing, og optisk burstsvitsjing der pakker, eller burst's av pakker svitsjes direkte i det optiske laget med optiske svitsjer. De nevnte teknikker antas å begynne å bli kommersielt interessante om omtrent fire år.

De fem dimensjoner

Siden optisk signalprosessering fremdeles er i sin barndom, er det svært begrensede muligheter for å signalere ulike typer informasjon som for eksempel adresseinformasjon. Dimensjoner som er tilgjengelig for overføring av informasjon i en optisk fiber er:

Intensitet, tid, frekvens, fase og polarisasjon. Alle disse dimensjonene er opp gjennom årene foreslått benyttet til ulike formål.

Modulasjonsformatene som benyttes i optiske linker og nettverk i dag er basert på NRZ og RZ formatet der Intensitet varieres mellom et minimum og maksimumsnivå. Signalene er tidsmultiplekset med en datarate på mellom 2,5 og 40 Gb/s. I optiske linjesvitsjede nettverk benyttes den optiske frekvensen til å multiplekse flere tidsmultipleksede kanaler på en fiber (WDM). Den optiske frekvensen er også foreslått brukt som merkelapp i optiske nettverk der rammeverket fra MPLS benyttes. Fase er foreslått benyttet som modulasjonsform for å øke spektral effektivitet, gjerne i kombinasjon med polarisasjon.

15 Optisk pakkesvitsjing, adresse, QoS og signalering

I forbindelse med optisk pakkesvitsjing er overføring av adresseinformasjon i form av en header eller label, en problemstilling. Normalt i en elektronisk ruter sendes headeren i starten på pakken eller rammen, og adresseinformasjon og nyttelast er dermed tidsmultiplekset. Med bruk av optiske komponenter er det vanskelig å demultiplekse i tidsplanet. Overføring av adresseinformasjon separat fra nyttelasten er derfor foreslått utført på ulike måter. Adresse og nyttelast skilles ved å bruke separate optiske bølgelengder, gir dårlig utnyttelse av bølgelengdene. Bruk av en separat frekvens innenfor den optiske bølgelengden, såkalt Sub Carrier Modulation (SCM), som utnytter den optiske båndbredden bedre enn når en separat bølgelengde benyttes, men som kan gi forringelse av nyttelastsignalet. I IST prosjektet "STOLAS" foreslås det å benytte fasemodulasjon for modulasjon av pakkeheader separat fra nyttelasten, også denne metoden kan gi forringelse av signalkvaliteten i nyttelasten.

Kjente prinsipper

- 1) Bruk av polarisasjon for multipleksing/demultipleksing av to datakanaler (polarisasjonsmultipleksing) på en fiber er et kjent prinsipp. Det er derfor kjent at man generelt kan skille informasjon med denne metoden.
 - 2) Bruk av polarisasjon til å finne start og stopp på en bit-sekvens er kjent, altså signalering ved å skifte polarisasjonstilstand
 - 3) Å skille ulike optiske datakanaler med polarisasjon på samme måte som ulike optiske datakanaler kan skilles på bølgelengde. Optiske add/drop enheter basert på å skille mellom ortogonale polarisasjoner er i likhet med liknende enheter som skiller ved bruk av bølgelengde
- QoS differentiation and header/payload separation in optical packet switching using polarisation multiplexing

Introduction

Optical packet switching (OPS) is promoted as a way to overcome the electronic bandwidth bottleneck. However, if OPS nodes are to be realised, they must also prove to be cost effective. In this paper we propose using polarisation multiplexing for a low-cost separation and reinsertion of control information in OPS, as well as for optical differentiation between Quality of Service (QoS) classes. The two applications can be performed simultaneously or separately.

Several techniques have been proposed for in-band header encoding, like serial header, Sub-Carrier Modulation (SCM), and Frequency Shift Keying (FSK). However, they require advanced components for separation of header and payload, and reinsertion of new headers. To erase old

header, before a new one can be inserted, per input wavelength, serial header requires a fast optical gate e.g. a Semiconductor Optical Amplifier (SOA), while SCM and FSK need an optical wavelength converter. This
 5 increases component count of complex and yet technologically immature components. Furthermore, if separation of packets belonging to different QoS classes is desirable, it will normally be done based on electronic processing of the header information, hence not all-
 10 optical.

The technique proposed here overcomes these drawbacks by using orthogonal States Of Polarisation (SOP) for separating packets and sending control information. By using a Polarisation Beam Splitter (PBS) per wavelength
 15 for header/payload separation, the complexity and cost may be reduced significantly, compared to the solutions mentioned above.

A highly efficient optical packet switching node design supporting guaranteed service

20 Introduction

The traffic volume of Internet is reported to show a significant increase despite the downturn of the telecommunication industry. Hence, increasing parts of the traffic in the transport network origins from packet data.
 25 For obvious economic reasons, new switching techniques should first be introduced at the time they show maturity and cost effectiveness. Hence there is a need to develop flexible optical networks supporting a seamless migration from an optical circuit switched (OCS) to an optical
 30 packet switched (OPS) backbone network.

In a statistical multiplexed packet switched network, services like constant delay, and no packet loss, can not be guaranteed due to the very nature of statistical

multiplexing. This may preclude the use of strict real-time applications, where delay is critical, and packet loss should be at an absolute minimum, like e.g. for remotely controlled surgery. Guaranteed service (GS),
 5 without contention causing packet loss, and a fixed delay, can however be offered if the packets are sent through a network following a path with pre-assigned resources, like in a Static or Dynamic Wavelength Routed Optical Network (S-WRON or D-WRON). D-WRONs increases throughput
 10 efficiency, compared to S-WRONs, by dynamically reconfiguring the wavelength paths to adapt to the traffic demands. However, the control plane operates on a ms to s timescale, and cannot be optimized to the bursty traffic patterns of OPS, where packet durations are typically in
 15 the μ s range. Therefore, not even D-WRONs can achieve the throughput efficiency and granularity of statistical multiplexing. In this paper we propose combining the properties of a statistically multiplexed packet switched network (OPS) with the GS enabled by optical circuit
 20 switched networks (like S-WRON/D-WRON) in a single optical network layer. This requires that the circuit switched GS packets and the OPS packets efficiently share the data layer resources. We propose a node design that allows full sharing of link bandwidth, and that allows a migration
 25 from a S-WRON to the more efficient combined network, by adding OPS capability. The efficiency of the node is studied using a simulator.

Muligheter for pakkesvitsjen

Pakkesvitsjen kan være dels optisk og dels elektronisk,
 30 eller heloptisk som beskrevet i de to avsnittene i dette kapittelet.

Det er i EP 07944684 A1 beskrevet et optisk pakkesvitsjet nettverk med en eller flere noder og en transmitter som sender polariserte pakkesignaler. Pakkesignalene
 35 inneholder en header og nyttelast som er skilt fra

hverandre ved hjelp av ortogonal polarisering. Vider er det kjent fra CA 2352113 en optisk kommunikasjonsmetode der det anvendes høyhastighets polarisert bit innfelling. Metoden går ut på å bruke polarisert bit innfelling for å
 5 skille datapakker fra hverandre i stedet for å multiplekse datastrømmer fra forskjellige modulatorer. Dette øker hastigheten for overføring av data i et optisk nettverk.

Kort beskrivelse av oppfinnelsen

Den foreliggende oppfinnelse søker å avhjelpe de foran
 10 omtalte problemer knyttet til dagens kjente løsninger, idet

Kort beskrivelse av tegningene

De vedlagte tegninger som er inkludert i og utgjør en del av spesifikasjonen illustrerer utførelser av den
 15 foreliggende oppfinnelsen og, sammen med beskrivelsen tjener den til å forklare prinsippene med oppfinnelsen.

Figur 1 viser pakker tilhørende to ulike QoS klasser tilordnes relativt ortogonale polarisasjonstilstander. Det blir dermed mulig i mottakeren å skille de to
 20 prioritetsklassene optisk ved bruk av en enkel polarisasjons strålesplitter.

Figur 2 viser the proposed node design. The resources used in the 1-switch and packet switch are shared. The number of inputs needed equals the number of input fibres X the
 25 number of link-wavelengths, GS = Guaranteed Service. & = Optical And Gate.

Figur 3 viser experimental setup. PC = Polarisation Controller

Figur 4 viser Figure 4, Sensitivity curves for the two signals, both for back-to-back (stippled lines) and at the egress node. Modulating both transmitters simultaneously.

Figur 5 viser Figure 5, The OPS part of the node is shown as an embedded part of an S-WRON node with a hardwired cross coupling matrix. In the S-WRON configuration example, each of the nodes connected to the inputs have 'k' wavelength-connections available to each of the outputs. The fixed wavelength converters enable on-line reconfiguration of the S-WRON. FDL = Fibre Delay Line, n = number of link-wavelength. N = Number of link inputs

Figur 6 viser Figure 6 (top, 32 l) and 7 (below, 128 l), X/Y-axis: Number of buffer interfaces/PLR. Error bars marks 95% confidence interval. No GS = pure BE system.

Figur 7 viser

Figur 8 viser Figure 8, skisse av hybridsvitsjen. Ruterer kan håndtere to QoS klasser, Beste effort og en første prioritets trafikk. Lysets polarisasjon brukes til å signalere QoS klassen. Best effort håndteres elektronisk, første prioritets trafikk optisk. I den optiske svitsjen er det bølgelengden som bestemmer hvor pakken forwardes.

Figur 9 viser Fig.9, A scalable design with QoS priority. Whether the packet will have priority or not, is decided by the state of polarisation of the packet at the input.

Figur 10 viser Figure 10, A network with a number of nodes and QoS connections between some of these.

Figur 11 viser Figure 11, The COST 266 reference scenario. It has a total of 37 nodes, and a maximum node degree of 5.

Detaljert beskrivelse av oppfinnelsen

Bruk av polarisasjonssignaler

En kan tenke seg at signaleringen kan brukes på flere alternative måter:

- 5 a) Synkronisering, polarisasjonstilstanden endres ved start av hver pakke.
- b) Header og payload i pakke skilles med orthogonale polarisasjonstilstander
- 10 c) QoS klasser skilles ved å tilordne pakker som skal behandles med ulik prioritet, ulik polarisasjon på sendersiden.

I figur 1 er det gitt et eksempel på hvordan polarisasjonstilstand kan benyttes til optisk å skille mellom to forskjellige QoS klasser. Samme prinsipp kan
 15 benyttes til å skille optisk mellom en header og en payload. Metoden kan, med bruk av en polarisasjonsstrålesplitter, skille informasjon uavhengig av bølgelengde. Sendes et WDM signal med mange bølgelengder inn på splitteren, vil splitteren fungere som en
 20 demultiplekser av header og payload (QoS klasser) for alle bølgelengdene.

Polarisasjon er tidligere foreslått brukt til synkronisering i optiske tidsdelt multipleksede systemer (OTDM). I et system der N rammer tidsmultiplekseres sammen,
 25 tilordnes den første rammen i hver sekvens av N rammer en polarisasjonstilstand som er orthogonal til de andre rammenes tilstand. I mottakeren benyttes denne informasjonen til å ekstrahere en rammeklokke som benyttes ved demultipleksing.

Applications

Figure 2 illustrates the proposed principle. Header and payload separation is implemented by sending the header in an SOP labelled '1', and the payload in SOP '2', orthogonal to '1'. Separation is done using a PBS, allowing full transparency with respect to bitrate and signal format for both header and payload.

Additionally, if a very high QoS is needed with a Guaranteed Service (GS) with respect to packet loss and delay, like e.g. remote image guided surgery, the GS packets may be forwarded solely on the basis of their wavelength information using a wavelength router. These packets can be separated from e.g. Best Effort (BE) packets by transmitting BE packets in SOP '2', while GS packets are transmitted in the SOP '1', like in figure 2. GS packets will then pass through a wavelength routed network allowing GS, while BE packets will be interleaved with the GS packets at the output of each node, increasing the utilisation of the links.

Both the described applications can be combined. GS packets will then be sent in SOP '1', without an orthogonal polarisation header, while BE packets will be sent in the SOP '2' with a simultaneously transmitted header in SOP '1'. When a signal is observed in SOP '1', with a signal simultaneously present in SOP '2', the signal in SOP '1' is recognised as the header of a BE packet. If there is no signal simultaneously present in SOP '2', the signal is recognised as a GS packet. When using this method, detection of the simultaneous presence of signals in the two SOP's enables distinction of GS packets and BE headers. If serial BE header is used, distinction can be implemented sending the signals from the two SOP's into an optical AND gate. The GS packets in SOP '1' are forwarded through the AND gate if SOP '2' is

high, while if SOP '2' is low, a BE header in SOP '1' is present, and blocked by the gate.

If only one application is implemented, BE and GS packets, or a header and a BE packet, can be sent simultaneously in both SOPs. This has the potential of doubling the link's bandwidth utilisation.

Experiment

The transmission properties of the principle have much in common with polarisation multiplexing: Depending on the fibre's birefringence, PMD and the link distance, signals are depolarised. However, unlike conventional polarisation multiplexing, where a polarisation demultiplexing is done only at the receiver node, our technique includes polarisation demultiplexing, polarisation, SOP re-alignment and polarisation multiplexing in all intermediate "core nodes". This increases tolerance to depolarisation and changes in SOPs, thereby allowing longer transmission distances.

In our experiment, we demonstrate the quality of the signal path through a network model performing one of the described applications. The experimental set-up, corresponding to a network consisting of an ingress node, a core node and an egress node, is shown in figure 3. Two optical transmitters on the same wavelength are modulated at 2.488 Gb/s using two separate and decorrelated bit generators with PRBS of length $2^{11} - 1$. The signals are combined using a polarisation maintaining (PM) coupler, and amplified using an EDFA. After the first 25 km SMF link, the signals arrive at the "Core Node". A manual Polarisation Controller (PC) ensures an ideal SOP to allow optimum splitting of the two signals in a PBS. To emulate forwarding of the signals, the two arms are combined using a PM coupler, and sent to the receiver node, through the second 25 km SMF link. Here, the two signals are again

realigned and separated, before sent to the receiver. Power penalties are found comparing transmission path and back-to-back Bit Error Rate (BER) curves in different configurations. Because of the polarisation variations occurring in the fibre due to variations in the fibres environmental conditions, like temperature variations, SOPs at the PBS inputs must be continuously monitored and optimised. The frequency of the variations caused by the environment is normally lower than an Hz; automatic polarisation optimisation can therefore be used.

Two different transmission schemes, illustrating the two proposed applications, were tested. The transmission characteristics of the header-payload separation is measured using modulation on both transmitters, while segregation of packets belonging to different QoS classes is done by modulating only one transmitter at a time, leaving the other in CW mode. We experienced that the most critical application is when modulating both polarisation states. However, as shown in figure 4, segregating packets was demonstrated with a very moderate penalty. The experimental points are interconnected by a linear fit, taking all but the very last measurement of the two egress node series into account. These are omitted because, during the measurement, drift in absolute SOP's, thus sub-optimum header-payload separation, occurred. This can be avoided using automatic PC (not available for the experiment). As shown in figure 4, a maximum penalty of less than 0.5 dB can be observed at a BER of 10^{-9} .

Conclusion

We have proposed and investigated the use of polarisation multiplexing for header and payload separation and for optical QoS differentiation in optical packet switched networks. The principle of a packet switch node is described and the quality of the signal path through a network model is experimentally verified. Using this

principle, the need for complex costly components is significantly reduced, and optical QoS packet segregation is achieved. A maximum penalty of only 0.5 dB was observed at the receiver node after passing the suggested optical packet switch node and 2 X 25 km of SMF.

Node design

The proposed node design is shown in figure 5. An OPS module, using the same principles as known from S. Bjornstad et.al. "A scalable optical packet switch for variable length packets employing shared electronic buffering". ECOC 2002, vol.3, 2002. P 4.7

is added to a S-WRON node. Packets are divided into two classes: "GS", that follows the pre-assigned S-WRON path, and a Best Effort class, "BE", without service guarantees, that is switched using the packet switch module. At the input, the two packet classes are segregated by setting 1x2 switches based on information in a header, or as shown in the figure 5 by using orthogonal States Of Polarization (SOP). Then each of the polarization states is assigned to each of the service classes.

Since the GS packets destinations are decided by the configuration of the cross coupling matrix and the individual wavelengths of the packets, like in figure 5, GS headers are superfluous. Since service class segregation is achieved using SOP, contrary to other proposed principles of optical QoS separation using reservation of wavelengths in an OCS network, the wavelength domain can be entirely devoted to wavelength routing purposes.

If a GS packet arrives at the switch, the control electronics register that a packet is present at the input before the packet is delayed in a FDL corresponding to the duration of a maximum sized BE packet, D_{BEMAX} . The output

for which the packet is scheduled is then reserved. If a BE packet is currently propagating through the reserved output, it will not collide with the newly arrived GS packet, because of the delay in the FDL. Alternatively, the output can be reserved D_{BEMAX} in advance of the GS packet arrival by sending a control packet. If SOP is used for segregating the packet classes, the control packet should be sent in the same SOP as the GS packet, enabling simultaneous transmission with potentially earlier transmitted BE packets.

Performance analysis

Packet delay and packet loss is found by simulation. Independent, asynchronous traffic generators, generating fixed length packets are used. The BE packets have a length of 500 B, while the GS packets length is varied, and set to either 500 B or 50 kB. An output is reserved D_{BEMAX} before a GS packet that arrives at the input enters the output.

The packets interarrival times are negative exponential distributed (Poisson), corresponding to a load of 0.8 of a maximum load on each wavelength. Packet arrivals, both BE and GS, are uniformly distributed at the switch inputs. BE packet destinations are uniformly distributed, thereby also among the outputs. The GS packets are forwarded to a fixed destination and wavelength, uniformly distributed, hence avoiding congestion with other GS packets.

Electronic buffering is assumed, therefore the BE packets can stay in the buffer for an arbitrary period of time. There is no limit on the size of the buffer, however the registered maximum filling of the buffer was 632 packets. The use of a very large buffer is therefore avoided. Buffered packets are normally scheduled as soon as a destined output becomes available, but reordering of packets may occur in rare cases.

The node performance is analysed in a transport network for 32 and 128 wavelengths at a node-degree of 8, varying the number of buffer inputs. The maximum delay measured, was 0.21 times the packet duration, in the case of 60
 5 buffer inputs, 50 % GS traffic share, 50 kB GS packet length, also giving maximum buffer filling. This is normally much lower than the transmission delay and hence negligible. The simulation results showing PLR, for GS packet share of 10% and 50 % of the total traffic load,
 10 measured in bytes, are shown in figure 6 and 7, respectively.

In both figures we compare the performance with a system with only BE traffic. When the PLR for the pure BE traffic is 10^{-6} , for 32 wavelengths and a GS packet length of 500
 15 bytes, the degradation is two decades for a 10 % GS traffic share, while for 50 % GS traffic share the degradation is more than three decades. If a GS packet length of 50 kB is used, the 50% and 10% curves are overlapping, and the degradation is one decade. Figure 7,
 20 for 128 wavelengths, show the same tendency. At a pure BE system PLR of 10^{-6} , degradation can be observed for GS packets when the packet length is 500 Bytes. At a GS traffic share of 10%, the degradation is approximately one decade, and for 50 % GS traffic, the degradation is
 25 approximately three decades. Worth noticing is that when the number of buffer interfaces is further increased, causing lower PLR's, degradation is observed also when using GS packets of 50 kB length. At a pure BE system PLR of 10^{-7} , the degradation is one half of a decade and one
 30 decade for 10% and 50% GS traffic shares, respectively.

Figures 7 and 8 illustrates that the overhead caused by the reservation time is the main reason for the PLR degradation. Generally, a degradation increasing with the decreasing PLR and thus, number of interfaces, can be
 35 observed. When the GS packet length is large (50 kB), the degradation is low, independently of the GS traffic share.

However, when GS and BE packets have equal length, the degradation may be several decades. From the simulation results we conclude that the PLR penalty is low if the GS packets are much longer than D_{BEMAX} . Since GS packets are given absolute priority, the very low BE PLR penalty observed, even when 50 % of the total traffic is GS packets, may come as a surprise. However, when increasing the number of GS packets in the system, the number of BE packets are decreased, causing less problems with contention between BE packets and less load on the available buffer resources.

Conclusions

An OPS node design supporting GS without packet loss and with fixed delay, as well as a BE service class is proposed. The design supports a migration strategy from circuit to packet switching by starting with an S-WRON module and adding an OPS module. High capacity utilisation is obtained by interleaving statistically multiplexed BE packets with GS packets that follow a pre-assigned wavelength path. The penalty of introducing GS packets in the system is shown to be very moderate if the GS packets is much longer than the BE packets. Aggregation of GS packets into bursts must therefore be considered.

Hybrid elektronisk/optisk svitsj med QoS

25 Dette avsnittet beskriver en hybrid konstruksjon der en svitsj bygges opp med en optisk forwarding av en kvalitetsklasse (GS) og en elektronisk forwarding av en annen kvalitetsklasse (BE). Figur 8 viser en skisse av svitsjens oppbygging.

30 Svitsjen har to svitsjematriser, en elektronisk og en optisk svitsjematrise. Den elektroniske svitsjematrisen er mye tenkt å være lik dagens elektroniske svitsjer

svitsjematrise, og fungere sammen med kontrollenheten som dagens Best Effort svitsjer.

Den optiske svitsjematrisen er tenkt å fungere som en "bølgelengderuter". En bølgelengde inn sendes til en bestemt fiber og bølgelengde ut. Bølgelengden ut og fiberen ut settes ut fra bølgelengden og fiberen inn. I illustrasjonen i figur 8 brukes kun en fiber. Denne tilnærmingen har likheter med MPLS der bølgelengden kan betraktes som en label.

- 10 På inngangen splittes signalet avhengig av det optiske signalets polarisasjon. Fordelen med dette er at en rent optisk enhet kan brukes til å splitte trafikk som skal ha første prioritets håndtering og håndteres som "best effort". Løsningen forutsetter at avsenderne sorterer
- 15 prioritert trafikk og Best Effort trafikk ved å sende disse med relativt til hverandre ortogonal polarisasjon. Løsningen kan i prinsippet være et tilbygg til en elektronisk svitsj, der den elektroniske svitsjen beholdes slik den er i dag, og håndterer best effort trafikk, mens
- 20 den optiske bølgelengderuterer tar seg av førsteprioritets trafikk. Konstruksjonen blir da noe annerledes og noe mindre optimal en vist i figur 8. Det blir ingen mulighet for den elektroniske svitsjen å la den optiske svitsjen ta seg av trafikk når sistnevnte har ledig kapasitet.
- 25 Utnyttelsen av den optiske delen blir derfor noe mindre optimal, men konstruksjonen blir betydelig forenklet.

I figur 8 er det tenkt at et antall bølgelengder reserveres til den elektroniske svitsjen og et antall til den optiske svitsjen. Hvis den optiske svitsjen er et

- 30 tilbygg, kan dette bølgelengdeantallet være et fast antall, eller styrt sentralt. Hvis de to svitsjne er bygget sammen fra starten av, kan antallet bølgelengder enklere varieres og være dynamisk og håndteres internt i svitsjen.

Optisk svitsjing av både GS og BE pakker, med mulighet for elektronisk buffring (som foreslått i artiklene /7/ og /8/)

Optical packet switching combined with a GMPLS approach
5 for high QoS packets

Another design example is given in figure 9. By always delaying packets with high priority (QoS packet), outputs can be reserved so that the destined output is vacant when the packet occurs at the output of the optical buffer.

10 In this design BE packets may choose freely among all the wavelengths at the output of the switch. In the first stage of the switch the output wavelengths is chosen. The QoS packets bypasses this first stage, hence the QoS packets input wavelength will decide the output wavelength
15 at the output fibre. To which output fibre the packet is forwarded, is decided by the wavelength set by the packet switch's second row of wavelength-converters. In the third row of wavelength-converters, the wavelength will be set to a fixed wavelength matching the input wavelength of
20 specific input of a mux. Hence there is not possible changing the wavelength.

Contention resolution

Because there is not possible buffering the QoS packets for contention resolution in this design, a reservation
25 scheme will be necessary. Before a QoS packet is transmitted, a wavelength from the transmitter to the destination should be reserved. This implies that each of the receivers will simultaneously be able to receive QoS packets from a number of destinations limited to the
30 number of input wavelengths at the receiver end. To avoid contention, no more than one source will be allowed to generate packets to each of the input wavelengths in a node. Figure 10 illustrates this principle.

In the network shown in figure 10, when QoS information is sent from one node to another, say from node 4, to node 6, a path consisting of one or more wavelengths needs to be reserved all the way through the network, from node 4 to node 6. The reservation implies that no other nodes can transmit QoS information at the reserved wavelength if the wavelengths are sharing the same path (fibre) along the way. If two nodes were transmitting at the same wavelength, contention would occur. Since no buffering is available for QoS packets, packets would have to be dropped.

Wavelengths can both be reused, and added/dropped. As shown in the figure 10, at node N1, the incoming wavelength from node N2, named N2- 4, is dropped at N1, and reused for sending QoS packets from node N1 to node N6 (N1- 4).

Scalability

Normally the node degree in a transport network like this will be in the order of say 4-8. Also the total number of nodes in the transport network will be limited. In COST 266 a reference scenario for a pan European network is given. Figure 11 illustrates this network. In the network a total of 37 Nodes is present, and it has a maximum node degree of 5. The question is whether a static configuration of QoS resources will be sufficiently effective in a transport network. Whether this is true will depend on the amount of QoS traffic in the network, and the number of wavelengths in each node. The packet switch design described will be effective only when a high number of wavelengths is available. This is because the design relies on using the wavelength dimension for contention resolution. Number of wavelengths should therefore be 32 or more. When 37 nodes are present, a maximum of unique wavelengths will be necessary in order to have a full mesh QoS network available.

Dynamic wavelength allocation for scalability

If a dynamic wavelength allocation scheme is employed, wavelengths can dynamically be set up and taken down on demand. This will increase the utilization of the resources available for transmitting QoS packets, since it will allow dynamic changes in the traffic load. If the node in figure 9. is slightly modified, replacing the fixed wavelength converters at the output with tunable wavelength converters, the wavelength for a QoS path can be allowed to change along the way. This will allow a higher reuse factor of the wavelengths in the network. However, a technical problem when multiplexing the unpredictable wavelengths at the output of the tunable wavelength converters, has to be solved. Normally a low loss multiplexer will be wavelength sensitive. Other approaches to switching the wavelength in the node may be evaluated.

Transparent Dynamic line switching and/or Burst switching

The QoS packets do actually not need to be packets. They can be bursts of packets, i.e. burst switching can be performed, or it can be a semi-permanent line, i.e. line switching. It will all depend on the preferred approach. When a QoS packet arrives at the input of the switch, a change in the state of polarisation will be detected. Hence it is known that it is a QoS packet. At the end of a QoS packet, the state of polarisation has to be changed back to the "best effort state" so that when the QoS packet has passed the polarisation monitor, the switch will know the end of the packet. The output and the resources in the switch will then be freed, so that resources can be used by the Best Effort packets.

Since the start and stop of the QoS packets is detected only by change in state of polarisation, and QoS packets will never be passed to the buffer, there is no need to

know the content of the information in the QoS packets. The physical format of the QoS packet, like bitrate and modulation, can therefore in principle be varied. The limitations on the transparency will be set by the characteristics of the wavelength converters.

For forwarding of the QoS packets, the destination of the packet must be known in advance. This is for the switch to be able to set the wavelength converter in the second row of converters. The information about the QoS packet should be sent in advance. There are two approaches to this:

Burst switching approach: This principle should be used if there are few QoS paths in the network, and they will have to be reused often. QoS paths can be established for a very short period of time, corresponding to the length of a packet, or a burst of packets.

The information about the destination for QoS packets occurring at a specific input and wavelength is sent as a control packet. The control packet can be sent on a separate wavelength, or at the same wavelength, and will contain a header, telling the destination of the QoS packet(s). It does not need to contain information about the length of the packet or burst of packets, since the state of polarisation will tell the start and stop of the packets or burst. In burst switching, information about the arrival time of the packet is sent out in advance. This is for the immediate nodes to be able to reserve bandwidth during a, in the control packet, specified period of time. However since the QoS packets are always buffered in the switch in a optical fibre delay line, bandwidth reservation is not necessary in advance, it will be done when the QoS packet arrives at the switch. In addition, a protocol for distribution of the forwarding information will be needed. A table containing a mapping between the address information in the control packet and how to set the wavelength converters is necessary.

Line switching approach: This principle should be used when QoS paths will have a duration that is much longer than a burst of packets. The output wavelength of the wavelength converter will be set to a wavelength according to a table. The table will be updated by a protocol distributing the forwarding information. This implies that no address lookup will be needed when a QoS packet arrives, avoiding processing. However, there will be a mapping between a specified input (wavelength), and a specified output wavelength, that can be changed only by updating the table. The speed of the dynamic allocation of QoS paths will therefore be limited by the protocol updating the table.

Utilization of the QoS paths

The node design in figure 9. allows the QoS paths to be utilized by BE packets when QoS packets are not present. The lights state of polarisation is used for differencing between QoS and BE packets. Therefore, most of the capacity not used by the QoS traffic can be used by the BE packets by interleaving these packets in between the QoS packets or bursts. Technically, it is possible to transmit both QoS and BE packets simultaneously when the polarization is orthogonal. This implies doubling the capacity in the fibre, however this also implies a number of technical challenges with respect to the transmission quality of the signal, since interference between the signals in the two states of polarisation will occur.

Therefore, in this approach, BE and QoS packets are sent in a serial manner, avoiding degradation of signal quality due to interference.

When the node design in figure 9 is used, BE packets can be buffered and allocated a random wavelength along the path to its destination. This allows the capacity of the wavelengths, and also the wavelengths or paths reserved

for transmission of QoS packets, to be efficiently utilized. When no QoS packet is present at a reserved QoS path, a BE packet can, if it is available at one of the inputs or in the buffer, be switched to the reserved QoS path.

When a QoS packet occurs at the input of the switch (node), the packet will be sent in to an optical buffer with a delay corresponding to the length of the longest BE packet. While the QoS packet is in the buffer, the reserved QoS path at the output of the switch will be left vacant from the time when the last packet at this output has left the output until the QoS packet reaches the output of the buffer. The optical buffer will give a predictable delay, thus causing no jitter, with a magnitude insignificant compared to the transmission delay in the fibre between the nodes.



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P a t e n t k r a v

1. Et system for signalering innenfor optisk pakkesvitsjede nettverk
k a r a k t e r i s e r t v e d at det anvendes to eller
5 flere polarisasjonstilstander for signalering.
2. Et system i henhold til krav 1
k a r a k t e r i s e r t v e d at nevnte polarisasjonstilstander endres ved start av hver nye pakke.
- 10 3. Et system i henhold til krav 1
k a r a k t e r i s e r t v e d at nevnte polarisasjonstilstander endres mellom hode og nyttelast for å skille nevnte hode fra nevnte nyttelast innenfor den respektive pakke.
- 15 4. Et system i henhold til krav 1
k a r a k t e r i s e r t v e d at de forskjellige polarisasjonstilstander anvendes for å skille QoS klasser.
5. Et system i henhold til krav 4
k a r a k t e r i s e r t v e d at QoS klassene
20 bestemmes ved at avsender styrer polarisasjonstilstanden
6. Et system i henhold til krav 4
k a r a k t e r i s e r t v e d at det er den deriverte av nevnte polarisasjonstilstand som anvendes for å skille en eller flere QoS klasser.
- 25 7. Et system i henhold til ett av kravene 1-3
k a r a k t e r i s e r t v e d at det anvendes en polarisasjonsstrålesplitter for å skille mellom to eller flere polarisasjonstilstander.



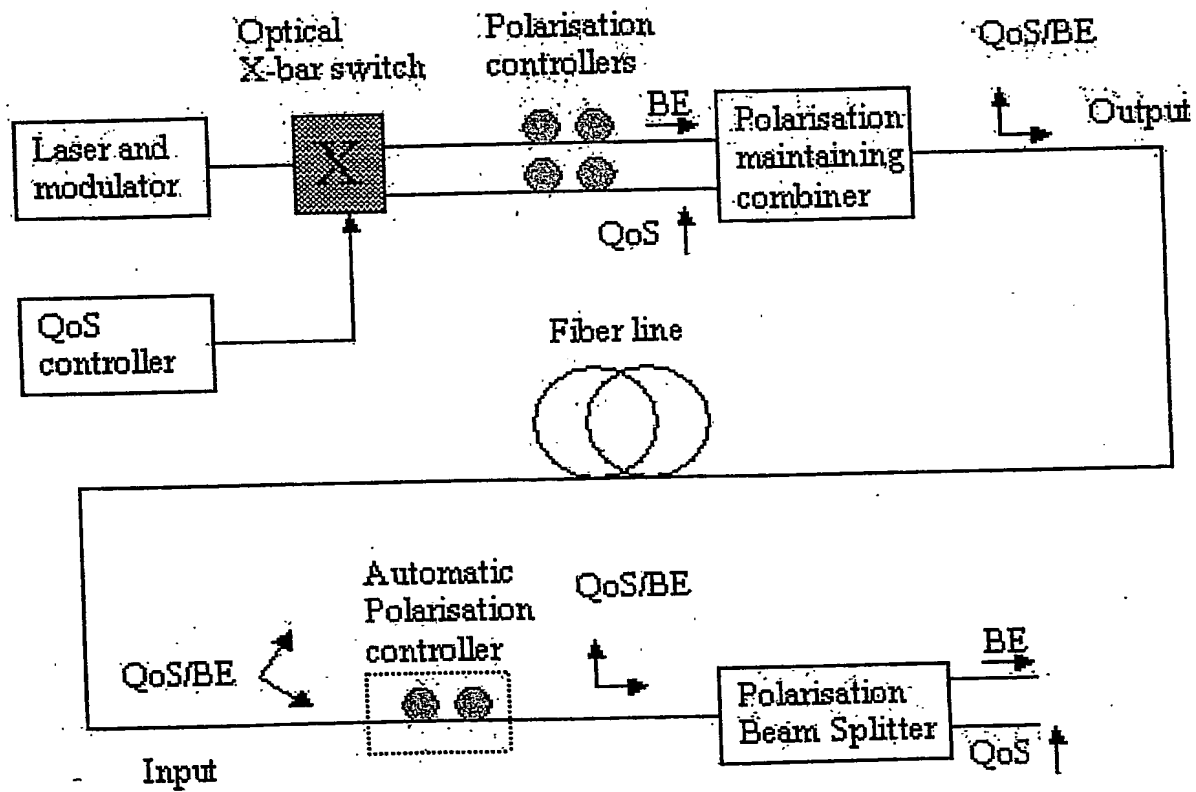


Figure 1



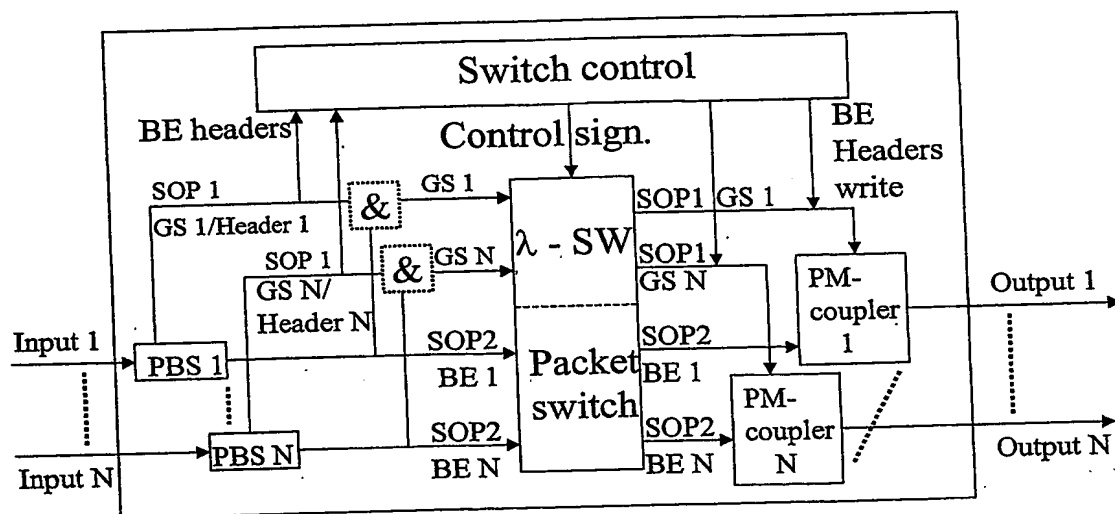
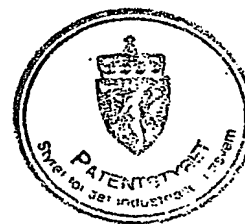


Figure 2



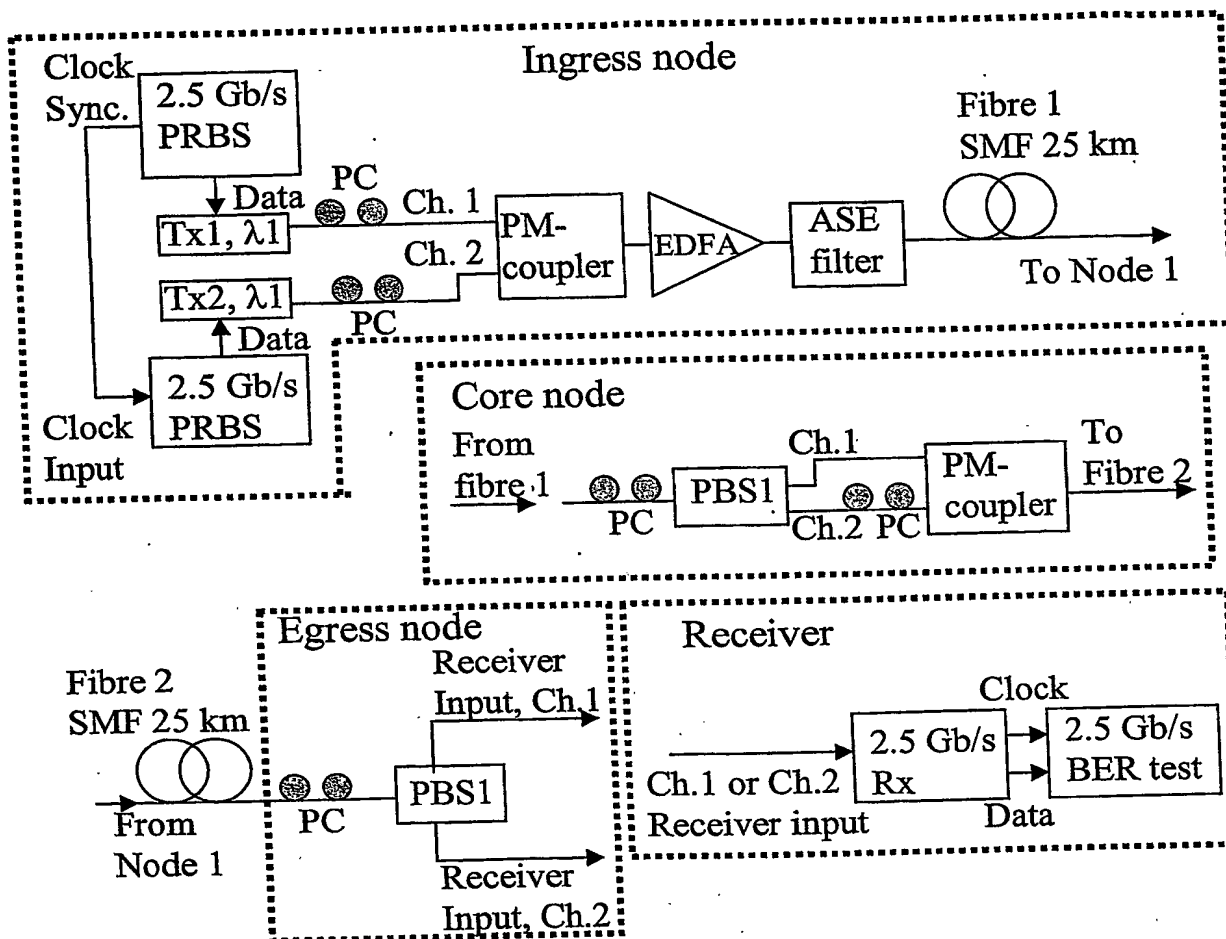
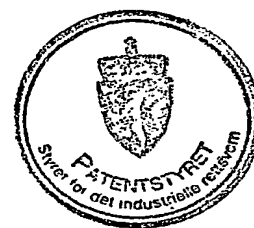


Figure 3



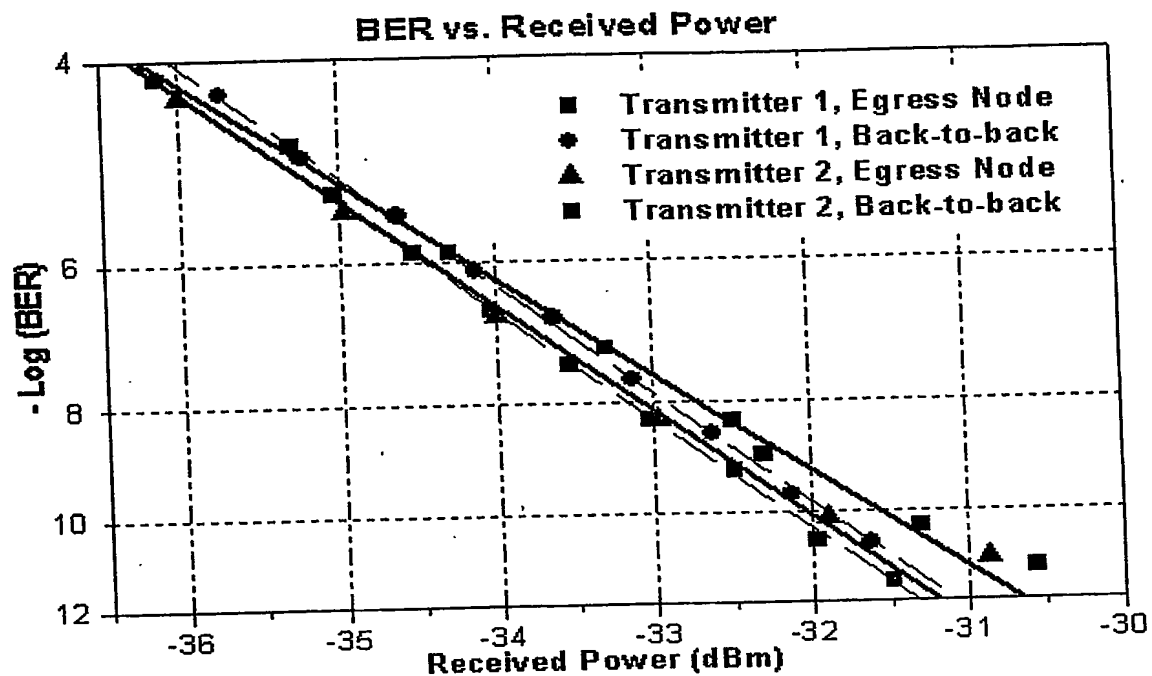
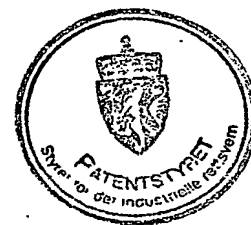


Figure 4



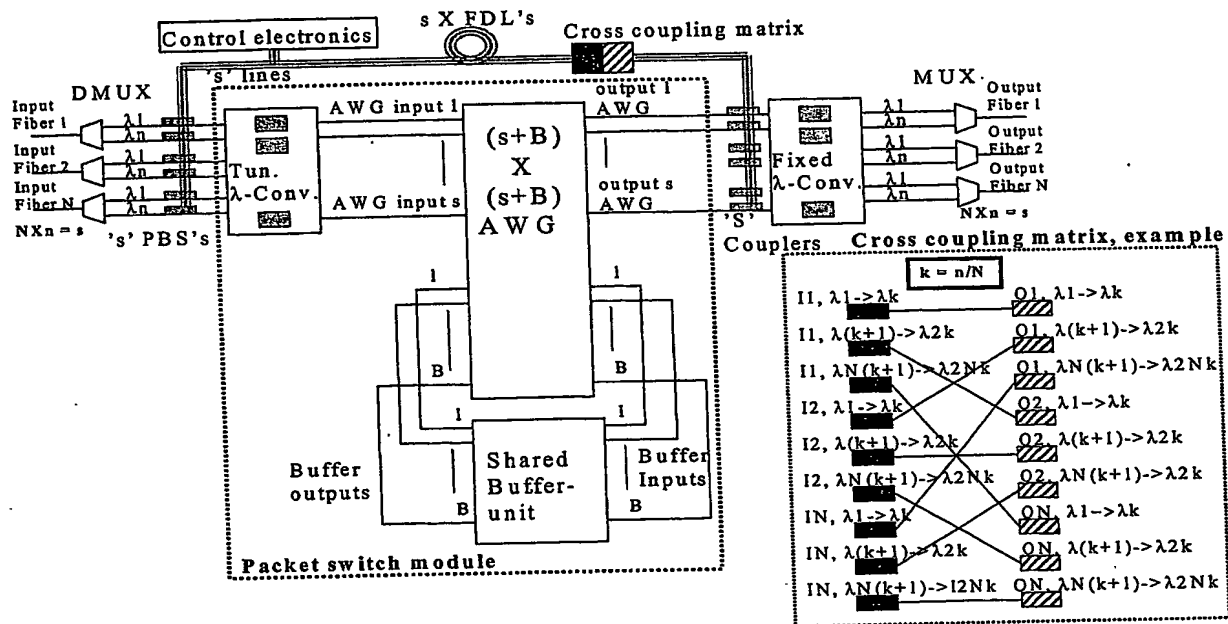
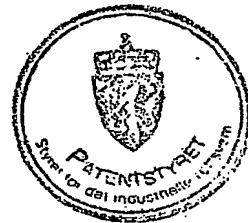


Figure 5



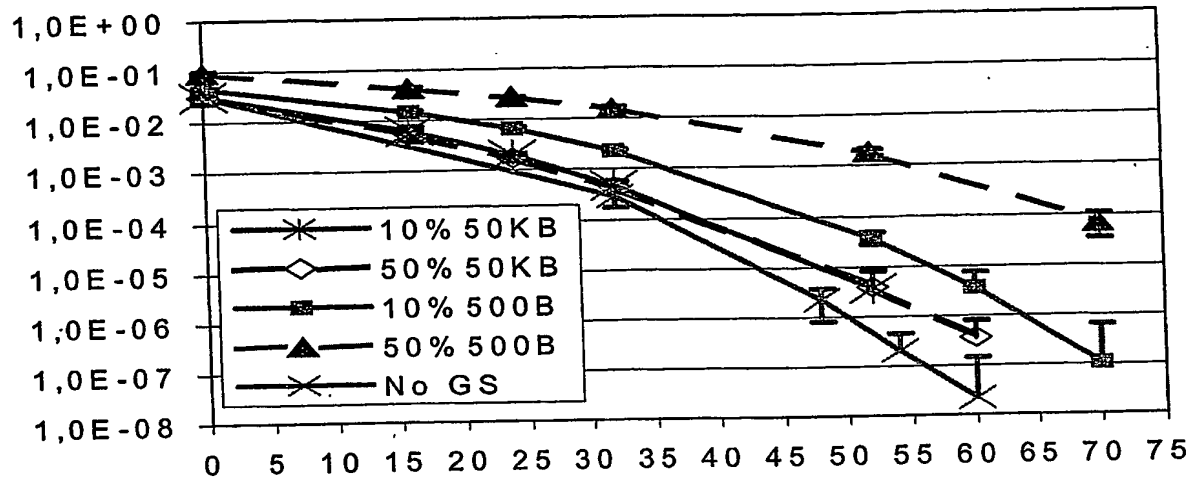


Figure 6

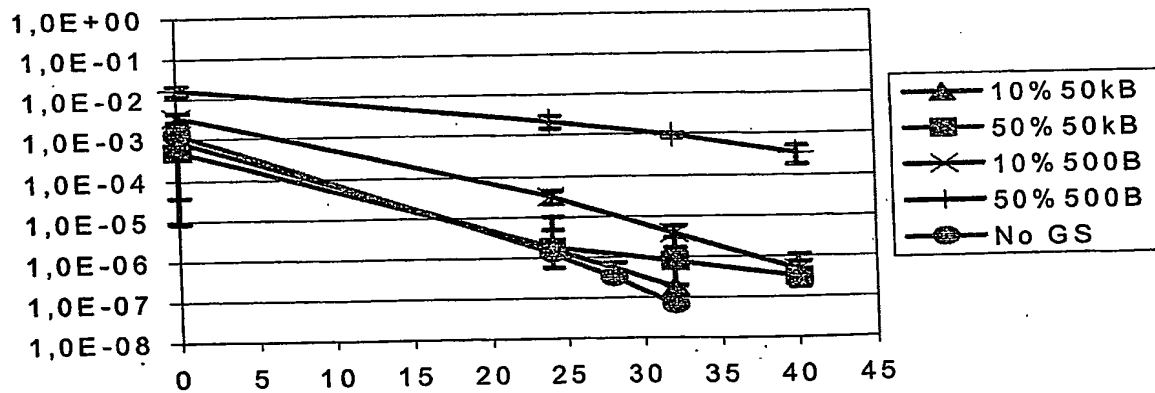
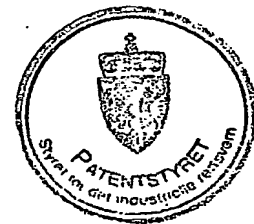
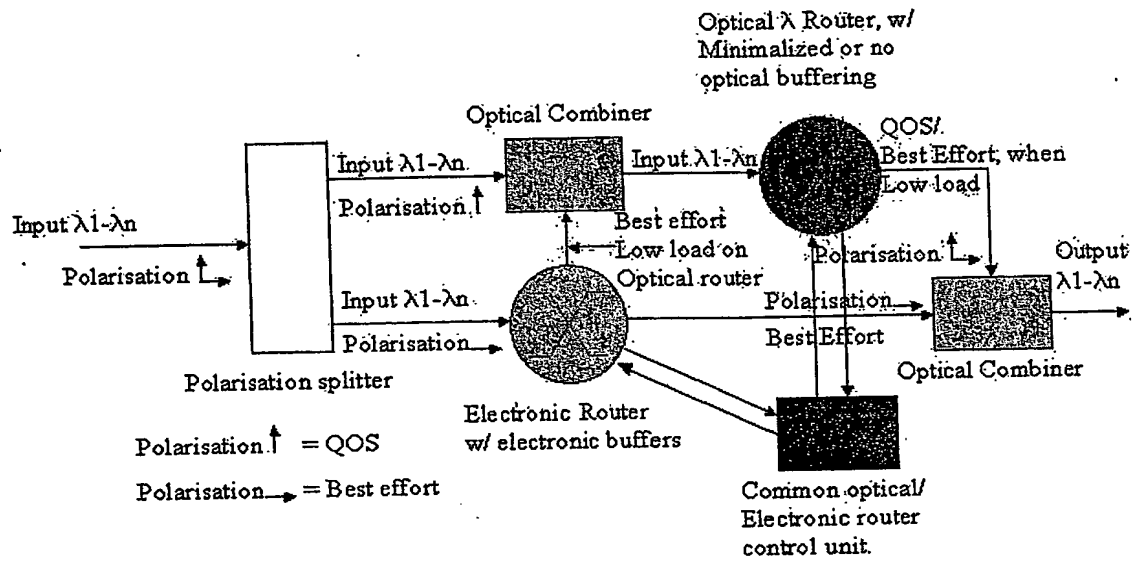
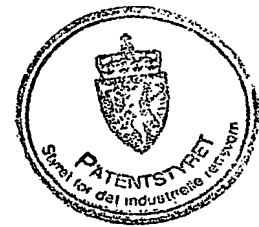


Figure 7





Figur 8



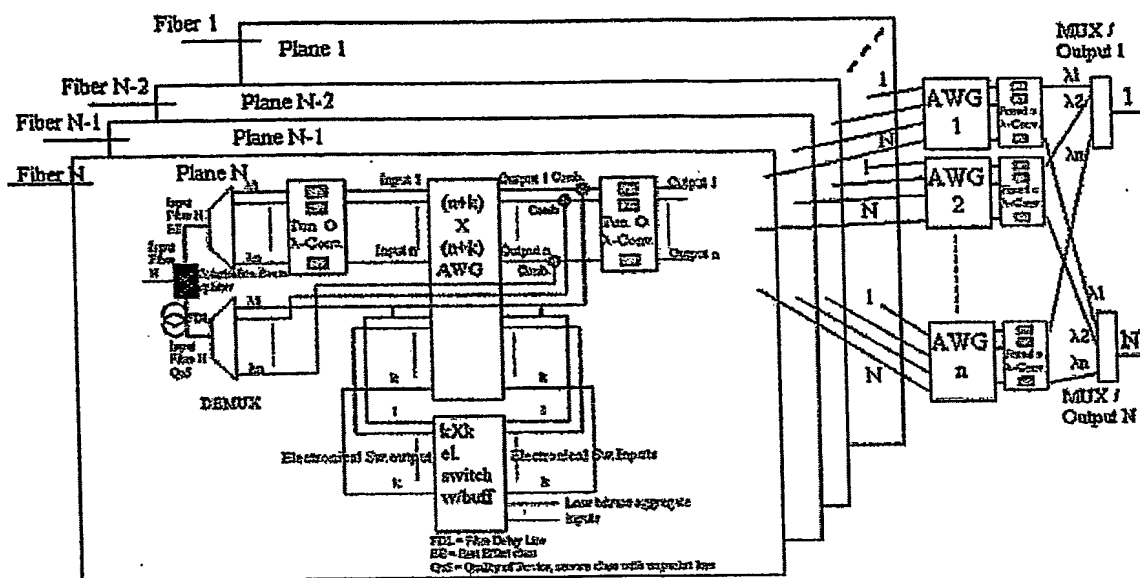
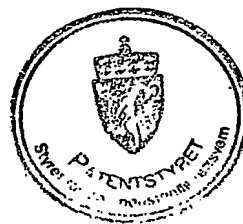


Figure 9



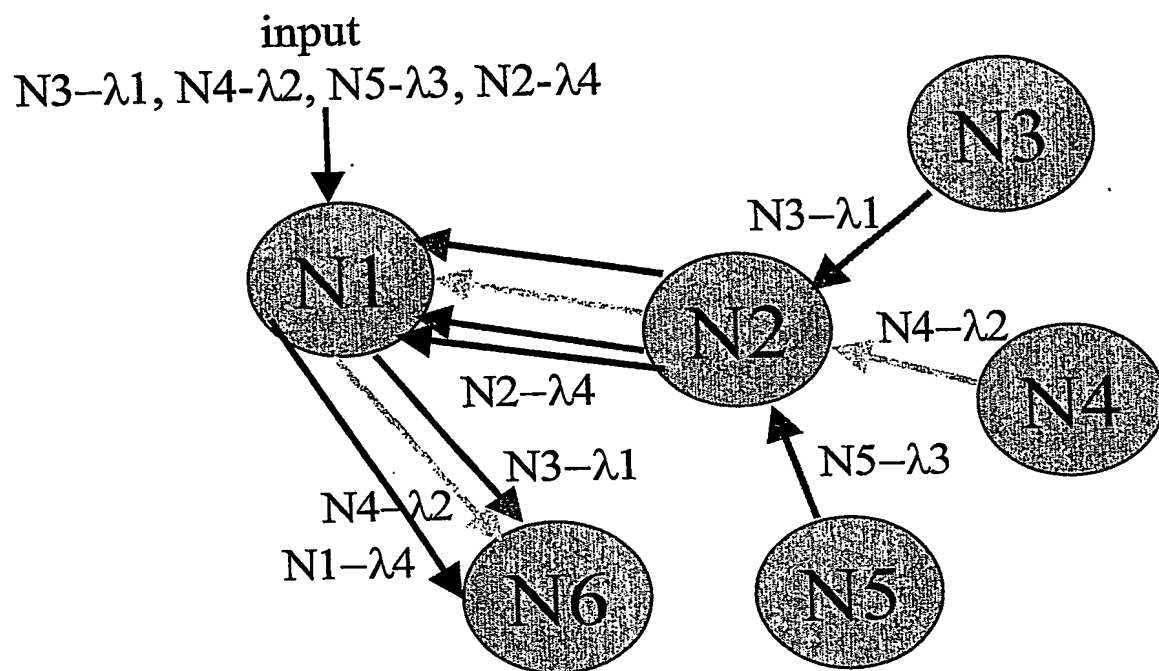


Figure 10



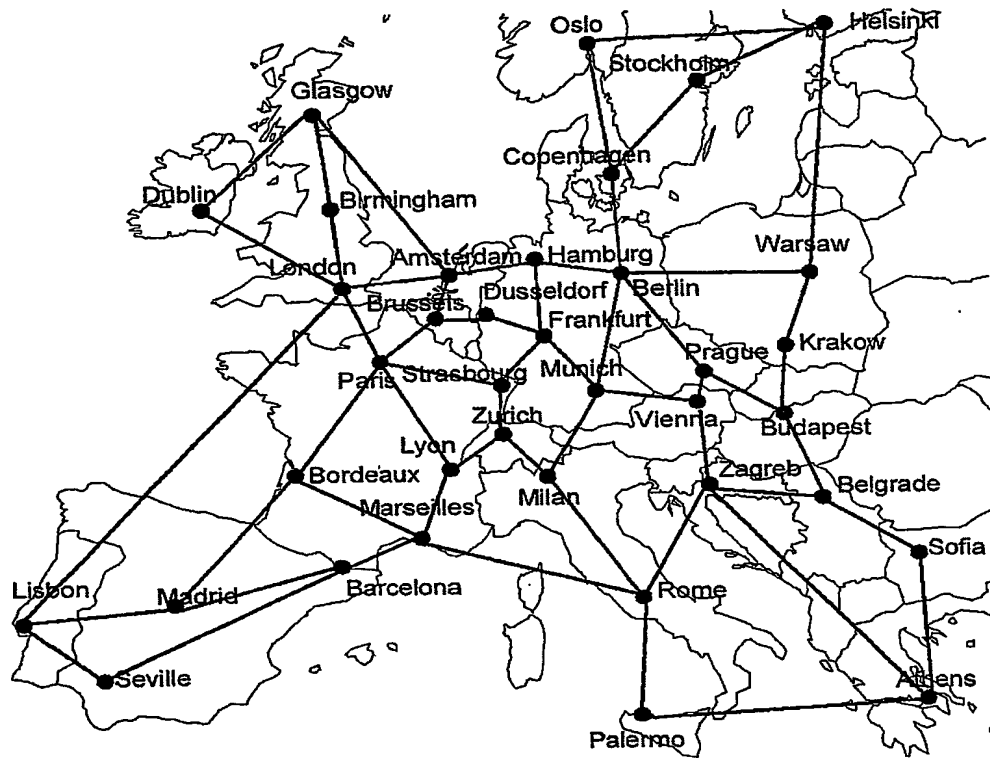


Figure 11



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